ZINC PHOSPHIDE BAITS AND PREBAITING FOR CONTROLLING RATS IN HAWAIIAN SUGARCANE

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Abstract: Sugarcane growers in Hawaii suffer crop damage and sugar losses to rats (*Rattus* spp.). We conducted tests to evaluate commercial zinc phosphide baits for reducing rat populations in Hawaiian sugarcane fields. During laboratory bioassays, mortality of black rats (*R. rattus*) and Polynesian rats (*R. exulans*) was higher ($P < 0.05$) with KFE Zinc Phosphide Prepared-Rat Bait and Hopkins Zinc Phosphide Pellets than with ZP Rodent Bait AG or Ridall-Zinc Rodent Field and Agricultural Bait. Hopkins Zinc Phosphide Pellets was the most effective ($P < 0.05$) bait against Norway rats (*R. norvegicus*), but low mortality with even this bait (70%) indicates the effectiveness of field applications may be variable. Single aerial broadcast applications of HGP Zincphos Oats or Hopkins pellets did not reduce ($P > 0.05$) the number of rats captured in sugarcane fields. Prebaiting with nontoxic grain according to manufacturers' instructions enhanced ($P < 0.05$) effectiveness of zinc phosphide oat bait, but not zinc phosphide pelleted bait ($P > 0.05$). However, substantial numbers of rats remained in all fields, regardless of rodenticide or whether fields were prebaited with nontoxic grain. Absorption of moisture and physical degradation may have reduced rats' acceptance of pellets. A more weather-resistant bait is needed to control rat depredations in wet and humid areas.

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Key words: animal damage control, black rat, crop protection, Hawaii, Norway rat, Polynesian rat, prebaiting, *Rattus exulans*, *Rattus norvegicus*, *Rattus rattus*, rodent control, rodenticide, sugarcane, zinc phosphide.

Rats have a negative effect on the Hawaiian sugarcane industry (Doty 1945, Hood et al. 1970, Tobin and Sugihara 1992). By gnawing on growing sugarcane stalks, they diminish yields, increase incidence of secondary infection, and reduce cane quality. Primary pest species are Norway and Polynesian rats that establish residences in field interiors; black rats cause damage along field perimeters (Fellows and Sugihara 1977, Tobin and Sugihara 1992).

Hawaiian sugarcane growers have used many poisons since the early 1900s to reduce rodent populations in fields (Pemberton 1925, Doty 1945). Since 1970, zinc phosphide has been the rodenticide of choice (Hood 1972, Tobin et al. 1990). A joint research effort by Denver Wildlife Research Center (DWRC) and the Hawaiian Sugar Planters' Association (HSPA) culminated in registration of a 1.88% active ingredient oat groat bait to control Polynesian rats, formerly the most abundant rat species in Hawaiian sugarcane fields (Hilton et al. 1972). Rat damage initially declined 40–70% in fields where zinc phosphide oats were applied (Hilton et al. 1972, Pank et al. 1973, Pank 1975).

Since 1970 Norway rat populations increased relative to those of Polynesian and black rats in Hawaiian sugarcane fields (Fellows and Sugihara 1977, Hirata 1977, Karim 1983, Tobin and Sugihara 1992). Zinc phosphide oats are less effective against Norway rats than the latter 2 species (Pank et al. 1976, Sugihara and Pank 1981, Tobin et al. 1990). Alternative zinc phosphide formulations may provide better results than zinc phosphide oats.

The larger body size of Norway rats compared with Polynesian rats and bait aversion due to sublethal consumption of bait may contribute to the inefficiency of zinc phosphide oat bait against Norway rats (Pank 1975, Prakash 1988, Shepherd and Inglis 1993). The median lethal dose (LD_{50}) of zinc phosphide for Norway rats is 40 mg/kg rat body mass (Hood 1972, Lund 1988) versus 23 mg/kg for Polynesian rats (Hood 1972). Thus, a 170-g Norway rat must consume about 13 zinc phosphide oat kernels to ingest an LD_{50} equivalent, compared with 3–4 oat kernels for a 70-g Polynesian rat.

Prebaiting with a nontoxic bait may enhance initial bait acceptance and increase mortality.

Studies of black rats in Florida (Lefebvre et al. 1978) and Polynesian rats in Hawaii (Hilton et al. 1972) demonstrated that prebaiting with nontoxic bait enhanced consumption of zinc phosphide baits. Nonetheless, plantations in Hawaii stopped prebaiting after adoption of aerial application techniques. In this study we compared laboratory efficacy of 4 commercial zinc phosphide baits on 3 rat species in Hawaii, tested effectiveness of 1 field application of each of 2 commercial zinc phosphide baits to reduce rat populations, and tested if prebaiting with nontoxic bait, according to manufacturer's instructions, improved bait effectiveness in the field.

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METHODS

Laboratory Bioassay

During November 1991, we used wire cage live traps (22 × 28 × 15 cm) to capture 110–120 animals each of Polynesian, Norway, and black rats in sugarcane fields and associated noncrop areas near Hilo, Hawaii. We transported animals to the DWRC Hawaii Field Station, dusted them with carbaryl insecticide powder, recorded mass and sex of each animal, and placed each rat in a stainless steel wire mesh cage (18 × 18 × 36 cm). Animals had ad libitum access to rodent laboratory chow and water and were quarantined ≥21 days before testing. At the end of quarantine, we randomly selected, reweighed, and transferred 300 adult rats (50 M and 50 F of each species) to clean cages in another room for testing.

We evaluated 4 rodenticides and a nontoxic bait: (1) Ridall-Zinc Rodent Field and Agricultural Bait (1.88% zinc phosphide), (2) ZP Rodent Bait AG (2.0% zinc phosphide), (3) Hopkins Zinc Phosphide Pellets (2.0% zinc phosphide), (4) KFE Zinc Phosphide Prepared-Rat Bait (1.88% zinc phosphide), and (5) untreated oat groats (control). The first 3 rodenticides were pelleted formulations; the KFE Zinc Phosphide bait was formulated on oat groats. Prior to testing, we sent 10 g of each formulation to the HSPA Experiment Station, Environmental Science Department (Aiea, Haw.) to determine zinc phosphide concentration.

To avoid confounding treatment effects with effect of animal mass, we ranked 50 males and 50 females (5 treatments × 10 animals/treatment) of each species by mass from heaviest to lightest. We then divided the 50 rats for each sex of each species into 10 groups by allocating the 5 heaviest rats to the first group, the next 5 heaviest rats to the next group, and so on, until each animal was assigned to a group. Finally, we randomly assigned the 5 treatments to the animals in each group with each animal per group receiving a different treatment.

We removed maintenance chow from cages and offered Norway, Polynesian, and black rats 20, 10, and 20 g, respectively, of their assigned bait. Twenty-four, 48, and 72 hours later, we collected and weighed uneaten and spilled bait. We dried bait moistened with urine or water by dehydrating it in a convection oven and cooled it in a desiccator before weighing it. We offered fresh bait at 24 and 48 hours and returned the maintenance chow to cages at the end of the feeding trial (72 hr). We recorded mortality and signs of toxicosis daily during the feeding trial and for 10 days post-treatment. At the end of post-treatment observation, we weighed survivors and euthanized them with carbon dioxide.

We calculated daily consumption for each animal by adjusting the mass of bait offered for moisture loss or gain and subtracting the combined mass of uneaten and spilled bait. We estimated changes in mass due to moisture loss or gain by placing 3 bowls of each treatment in the test room and weighing contents before and after each 24-hour period. Total consumption for the trial was the sum of daily consumption for each of the 3 days. We calculated milligrams of zinc phosphide ingested per kg rat body mass on the basis of assayed concentrations of test baits.

Data Analysis.—We conducted analyses of variance (ANOVA) (SAS Inst. Inc. 1988) for each rat species to detect differences in consumption among zinc phosphide baits and days, and among baits in initial (day 1) bait consumption. We used Duncan's multiple-range test with $P < 0.05$ (Saville 1990) to separate treatment and inter-

action means. We performed Chi-square tests to detect differences in mortality among species for each zinc pbosphide bait.

Field Evaluation

Study Area.—We conducted the study in 12 fields at Mauna Kea Agribusiness Co., a 6,000-ha sugarcane plantation north of Hilo, Hawaii. Fields were 40–60 ha, contained 16–26-month-old sugarcane, and had not received rodenticide treatments for the current crop. They ranged in elevation from 150 to 400 m and were bordered on ≥1 side by gulches or narrow dirt roads. Gulches were 50–100 m wide and 10–20 m deep and were vegetated by various species of introduced noncrop vegetation.

Treatments.—We evaluated HGP Zincphos Oats (1.88% zinc phosphide) in 6 fields and Hopkins pellets in the remaining fields. The HGP oat bait is commonly used by sugarcane growers and is similar to the KFE oat bait that we evaluated during laboratory bioassay but is no longer commercially available.

For each bait, we divided each of 6 fields into 3 comparable 13–20-ha sections and applied 3 treatments to the sections in each field (replicate) in a randomized complete block design with each section receiving a different treatment. Tbus, each treatment was applied in 6 different fields. The 3 treatments applied to each field were (1) 5.7 kg/ha of zinc phosphide bait, (2) 5.7 kg/ha of zinc phosphide bait preceded by an application of 11.4 kg/ha of untreated bait, and (3) a control. We used a Stearman biplane with a deflector fertilizer attachment to aerially broadcast baits. Bamboo poles with colored flagging placed at perimeter locations delineated field sections and guided the pilot while applying baits.

For the test with HGP oats, we broadcast untreated oat groats in 1 section of each field 7 days before we applied zinc phosphide oats to the same sections. For the test with Hopkins pellets, we followed the manufacturer's instructions and broadcast untreated wheat 7 days before applying zinc phosphide pellets to the same sections. We collected samples of zinc phosphide oats and pellets immediately before application and sent them to the DWRC Chemical Analysis Section and the manufacturer, respectively, for assay. We recorded rainfall daily beginning 3 days before the untreated bait was applied and continuing until 7 days after application of zinc phosphide bait.

Rat Populations.—We used live traps to index pretreatment relative abundance of rats without removing individuals. Because past studies have indicated a low recapture rate of rats with live traps (Lindsey et al. 1973, Sugihara et al. 1977, Lefebvre et al. 1985), we used snap traps to index post-treatment relative abundance of rats. We set traps in each field section for 4 consecutive nights before and after treatments were applied in each test. Similar to authors of other rodenticide field studies (Bruggers and Jackson 1981, Kaukeinen 1984, Richards 1988), we assumed total captures were an index of actual population size and a reliable indicator of population trends (Halvorson 1984).

We used a compass, machete, and distance-measuring device to establish a transect in the interior of each field section starting at an interior road and extending approximately 160 m into the field. Transects were ≥150 m from adjacent field sections and ≥30 m from noncrop areas. We placed 50 traps at 3-m intervals along each transect. At each trap site, we cleared sugarcane stalks and leaves from a 30- × 30-cm area to 1 side of the transect. We secured traps to the ground with numbered wire flags.

We used 50 live traps to index relative abundance of rats before treatments were applied in each field section. We scattered grated coconut along traplines 3 days before setting and baiting traps with coconut chunks. We checked traps between sunrise and 1200 for 4 consecutive days. We weighed captured animals, identified them to species and sex, and released them at the capture site. We rebaited and reset traps as necessary.

Ten days after applying zinc phosphide baits, we indexed post-treatment relative abundance of rats by setting 50 snap traps along each transect in the locations used for pretreatment live trapping. We prebaited transects with grated coconut 3 days before baiting traps with coconut chunks and setting them for 4 consecutive nights. Each morning we checked traps and rebaited and reset them as necessary.

Data Analysis.—We conducted separate analyses for pre- and post-treatment trapping periods of each field test. We employed a mixed model ANOVA (SAS Inst. Inc. 1988) with block as a random effect and treatment as a fixed effect to detect differences in number of animals captured per field section (replicate) for all species of rats and for Norway rats only. We used Duncan's multiple-range test ($P \leq 0.05$) (Saville 1990) to separate interaction means.

Table 1. Mean consumption of commercial zinc phosphide baits and mortality of 3 rat species during 3-day no-choice feeding trials, December 1991. Each bait was offered to 60 individually caged adult rats (10 M and 10 F of each species): untreated oats (control), KFE Zinc Phosphide Prepared-Rat Bait, ZP Rodent Bait AG, Hopkins Zinc Phosphide Pellets, and Ridall-Zinc Rodent Field and Agricultural Bait.

Bait	$\bar{x}$ initial body mass (g)	Consumption (g)				Zinc phosphide ingested (mg)/kg body mass		No. died/ no. tested
		Day 1		Days 1–3				
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
Norway rat								
Untreated oats	197	12.3	0.8	40.2	1.5	0.0		0/20
KFE oats	201	1.1	0.1	1.3	0.2	212.7	29.5	2/20
ZP pellets	197	1.7	0.3	2.4	0.4	254.5	43.6	2/20
Hopkins pellets	200	1.3	0.2	1.8	0.3	260.2	39.3	14/20
Ridall-Zinc pellets	197	0.5	0.1	0.7	0.1	99.5	20.4	1/20
Black rat								
Untreated oats	167	7.9	0.9	29.0	1.5	0.0		0/20
KFE oats	165	1.8	0.3	1.8	0.3	347.0	46.2	18/20
ZP pellets	168	2.1	0.6	2.5	0.6	280.4	64.8	11/20
Hopkins pellets	165	1.2	0.2	1.3	0.2	217.1	34.7	16/20
Ridall-Zinc pellets	168	0.7	0.1	0.7	0.1	98.7	15.5	12/20
Polynesian rat[a]								
Untreated oats	73	3.9	0.5	14.8	1.1	0.0		0/19
KFE oats	77	0.3	0.1	0.7	0.1	265.4	35.3	19/20
ZP pellets	77	0.3	0.1	0.4	0.1	117.1	23.2	10/20
Hopkins pellets	75	0.3	0.1	0.7	0.2	241.6	59.0	17/20
Ridall-Zinc pellets	76	0.2	0.1	0.5	0.1	162.4	19.6	14/19

[a] Only 48 Polynesian rats of each sex were available for testing.

RESULTS

Laboratory Bioassay

Assay concentrations of zinc phosphide were 3.10% (SE = 0.06) for KFE oats, 1.99% (SE = 0.03) for ZP pellets, 2.90% (SE = 0.03) for Hopkins pellets, and 2.33% (SE = 0.04) for Ridall-Zinc pellets. Consumption by black rats varied among days ($F = 8.09$; 2, 74 df; $P < 0.001$) but not baits ($F = 2.09$; 3, 37 df; $P = 0.12$), and was greater on the first day of feeding than on either of the 2 succeeding days ($P < 0.05$). Differences among days in consumption by the other 2 species varied by bait (Norway rats, $F = 2.85$; 6, 134 df; $P = 0.012$; Polynesian rats, $F = 2.08$; 6, 108 df; $P = 0.062$). Norway rat consumption of all zinc phosphide baits except Ridall-Zinc pellets was greatest on the first day of feeding ($P \leq 0.05$). Consumption by Polynesian rats varied ($P \leq 0.05$) among days only for Hopkins pellets, which was consumed in greater ($P \leq 0.05$) amounts on day 2 than on days 1 or 3. Three Polynesian rats that did not eat on day 1 accounted for most of the increased consumption on day 2. Mean days to death varied among all species and toxic baits from 1.3 to 3.0.

During the first day of the feeding trial, consumption varied among zinc phosphide baits for black rats ($F = 2.82$; 3, 72 df; $P = 0.045$) and Norway rats ($F = 5.14$; 3, 72 df; $P = 0.003$), but not Polynesian rats ($F = 0.41$; 3, 71 df; $P = 0.75$) (Table 1). On day 1 black rats consumed less Ridall-Zinc pellets than ZP pellets or KFE oats ($P \leq 0.05$), but not less than Hopkins pellets ($P > 0.05$). Norway rats offered Ridall-Zinc pellets ate less on the first day than did rats offered the other 2 pelleted formulations ($P \leq 0.05$), but not less than rats offered treated oats ($P > 0.05$).

Mortality was similar among black, Norway, and Polynesian rats offered Hopkins pellets ($\chi^2 = 1.37$, 2 df, $P = 0.50$) but differed among species for ZP pellets ($\chi^2 = 10.29$, 2 df, $P = 0.006$), KFE oats ($\chi^2 = 40.00$, 2 df, $P < 0.001$), and Ridall-Zinc pellets ($\chi^2 = 20.99$, 2 df, $P < 0.001$). Black and Polynesian rats exhibited similar susceptibility to each bait (Table 1). Mortality of these 2 species was greater than that of Norway rats for all baits except Hopkins pellets.

Field Evaluation

Oat Bait.—We captured 321 Norway rats, 27 Polynesian rats, and 5 black rats in live traps during 3,600 pretreatment trap nights. Norway rats averaged 90% of total rat captures among the 3 treatments. Captures for all rat species ($F = 0.84$; 2, 10 df; $P = 0.46$) and number of Norway rats ($F = 0.81$; 2, 10 df; $P = 0.47$) did not vary among treatments during pretreatment trapping (Fig. 1).

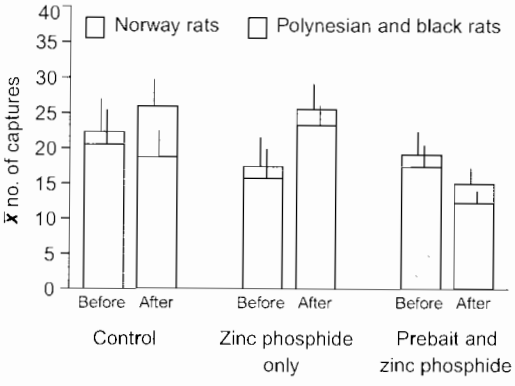

Fig. 1. Mean number of rats captured with live traps before and snap traps after zinc phosphide oats were applied in Hawaiian sugarcane fields, June–August 1991. We divided each of 6 fields into 3 comparable sections and randomly applied 3 treatments to the sections in each field (replicate) with each section receiving a different treatment. Treatments were (1) single aerial application of 1.88% zinc phosphide oats at 5.7 kg/ha, (2) aerial prebait application of untreated oats at 11.4 kg/ha 1 week prior to aerial application of 5.7 kg/ha of 1.88% zinc phosphide oats, and (3) experimental control. Lines above bars represent SEs for the mean number of captures of all species and the mean number of captures of Norway rats.

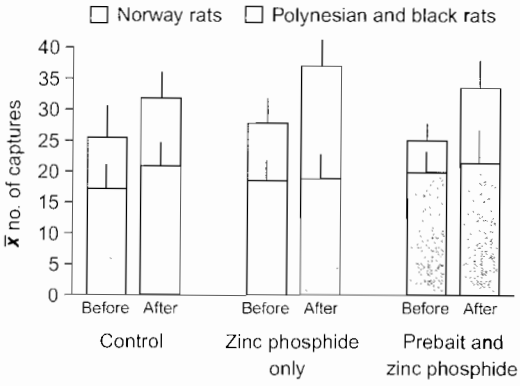

Fig. 2. Mean number of rats captured with live traps before and snap traps after zinc phosphide pellets were applied in Hawaiian sugarcane fields, October 1992–February 1993. We divided each of 6 fields into 3 comparable sections and randomly applied 3 treatments to the sections in each field (replicate) with each section receiving a different treatment. Treatments were (1) single aerial application of 2.00% zinc phosphide pellets at 5.7 kg/ha, (2) aerial prebait application of untreated wheat at 11.4 kg/ha 1 week prior to aerial application of 5.7 kg/ha of 2.00% zinc phosphide pellets, and (3) experimental control. Lines above bars represent SEs for the mean number of captures of all species and the mean number of captures of Norway rats.

Assay concentration of zinc phosphide in the oat bait was 1.96% (SE = 0.06). A cumulative average of 0.9 and 2.4 mm of precipitation fell within 48 and 96 hours, respectively, after applying zinc phosphide bait.

During 3,600 post-treatment trap nights, we captured 324 Norway rats, 71 Polynesian rats, and 3 black rats in snap traps. Mean number of Norway rats varied from 75 to 93% of all rat captures. Number of rats trapped of all species ($F = 16.3$; 2, 10 df; $P < 0.001$) and number of Norway rats ($F = 8.7$; 2, 10 df; $P = 0.006$) differed among treatments during post-treatment trapping. Mean number of captures of all species and of Norway rats was less ($P \leq 0.05$) in prebaited sections than in zinc phosphide alone or control sections (Fig. 1). Captures of all rat species and captures of Norway rats did not differ ($P > 0.05$) between the zinc phosphide without prebaiting and the control sections (Fig. 1).

Pelleted Bait.—Pretreatment live trapping during 3,600 trap nights yielded 333 Norway rats, 119 Polynesian rats, and 18 black rats. Norway rats composed 68–80% of all captures. Number of all rats ($F = 0.18$; 2, 10 df; $P = 0.84$) and number of Norway rats ($F = 0.16$; 2, 10 df; $P = 0.85$) did not vary among treatments during pretreatment trapping (Fig. 2).

Hopkins pellets were assayed at 2.00% (SE = 0.03) zinc phosphide. A cumulative average of 14.5 mm of precipitation fell within 48 hours after application; 27.9 mm fell within 96 hours. The soil and thick sugarcane-thatch layer remained moist following application, and Hopkins pellets became soft.

During 3,600 trap nights of post-treatment snap trapping, we captured 366 Norway rats, 239 Polynesian rats, and 9 black rats. Fifty to 67% of all rats captured in individual fields were Norway rats. Total number of rats ($F = 0.41$; 2, 10 df; $P = 0.67$) and number of Norway rats ($F = 0.09$; 2, 10 df; $P = 0.91$) trapped did not vary among the 3 treatments during post-treatment trapping (Fig. 2).

DISCUSSION

Available zinc phosphide baits have the potential for reducing field populations of black rats and Polynesian rats, but effectiveness against Norway rats is questionable. These results are consistent with other studies (Fellows 1977, Sugihara and Pank 1981, Tobin et al. 1990). The greatest mortality of Norway rats in the laboratory occurred with Hopkins pellets. The 70% mortality achieved with this bait met the U.S. Environmental Protection Agency's minimum

efficacy requirement for registration of rodenticides, but results were sufficiently low that benefits of operational use could be less than satisfactory.

Limited captures of Polynesian and black rats precluded assessment of field treatments for these species. We discuss field results in reference only to Norway rats. Aerial application of zinc phosphide oat bait alone had no apparent effect on rat captures. The lower number of rats trapped in prebaited sections relative to that in zinc phosphide only and control sections indicates that prebaiting enhanced effectiveness of the toxic oat bait, but substantial numbers of Norway rats still remained in prebaited sections after application of zinc phosphide oat bait.

Applying Hopkins pellets did not affect the number of rats captured in sugarcane fields, even if the fields were prebaited. We did not assess acceptance by rats of the wheat prebait. However, Hawaiian rats prefer oats over wheat (Doty 1945, Koehler et al. 1994). The manufacturer's instructions for Hopkins pellets specifies that wheat should be used for prebaiting, presumably because this is the major grain in the bait. A different formulation with oats as the main ingredient may be more palatable.

Absorption of moisture and physical degradation may have reduced rats' acceptance of pellets. Another pelleted zinc phosphide bait (ZP pellets) also was effective in laboratory bioassays (Sugihara and Pank 1981) but not in field trials (Fellows et al. 1982). The authors of the latter study attributed the lack of field efficacy to moisture absorption and rapid bait deterioration. Poor weatherability was implicated as the cause of similar discrepancies in Florida sugarcane (Lefebvre et al. 1985). Koehler et al. (1995) observed that Hopkins pellets retained their toxicity even when they absorbed moisture and became soft, and Guerrant and Miles (1969) reported that the toxicity of zinc phosphide baits remained high even after 2–3 days of moderate rainfall. These studies suggest that physical deterioration of the bait and reduced bait acceptance, rather than loss or degradation of the toxicant, were responsible for lack of field efficacy in our study.

Our methods did not enable us to distinguish resident survivors from rats that invaded depopulated fields from surrounding areas. We dyed the pelage of rats captured during the first field trial but could not reliably distinguish the marks. U.S. Department of Agriculture, DWRC, animal welfare regulations precludes notching ears or clipping toes of rats.

Previous radio-telemetry studies in Hawaii have shown that rats in mature sugarcane fields and adjacent noncrop areas move limited distances. Norway rats captured in sugarcane fields moved a maximum of 91 m, and rats trapped at field edges seldom ranged >30 m into the field (Nass et al. 1971). Polynesian rats were even more sedentary (Tomich 1970, Lindsey et al. 1973). In this study, we tried to minimize reinvasion by using large field sections (13–20 ha) as experimental units, locating trapping transects in the middle of the sections, and having a buffer of ≥150 m between each trapping transect and the edges of the treatment section.

Repeated applications during the past 20 years of ≤4 treatments of zinc phosphide during each 18–26-month crop cycle may have reduced effectiveness of this toxicant. Marsh (1987) reported reduced efficacy of zinc phosphide baits against ground squirrels (*Spermophilus beecheyi*) and voles (*Microtus* spp.) following repeated use in California. Other investigators (Prakash 1988, Shepherd and Inglis 1993) reported persistent (>7 months) bait aversion among wild Norway rats after only brief sublethal exposure to zinc phosphide. Further study is needed to determine whether poor bait acceptance, sublethal aversion, physiological resistance or tolerance, or some other factor is reducing field effectiveness of zinc phosphide baits in Hawaii.

MANAGEMENT IMPLICATIONS

Commercial zinc phosphide baits available for use in sugarcane fields are not effective for reducing Norway rat populations. Nonetheless, zinc phosphide remains the only toxicant registered for this purpose, and developing and registering an alternative toxicant for in-crop use would require years of research and development and probably cost >$1 million (Samuel et al. 1983, Fagerstone et al. 1990). Therefore, efforts should focus on improving effectiveness of zinc phosphide baits, including developing more weather-resistant formulations for use in wet and humid conditions. Long-range research should focus on identifying and registering an alternative toxicant, as well as developing such nonchemical control tools as resistant sugarcane varieties, nonlethal repellents, and physical barriers to prevent invasion of fields.

LITERATURE CITED

BRUGGERS, R. L., AND W. B. JACKSON. 1981. Suggested methods for determining the efficacy of vertebrate control agents in developing countries. Pages 15–28 *in* E. W. Schafer, Jr., and C. R. Walker, eds. Vertebrate pest control and management materials: third conference. Am. Soc. Testing and Materials Spec. Tech. Publ. 752, Philadelphia, Pa.

DOTY, R. E. 1945. Rat control on Hawaiian sugar cane plantations. Hawaii. Plant. Rec. 49:72–241.

FAGERSTONE, K. A., R. W. BULLARD, AND C. A. RAMEY. 1990. Politics and economics of maintaining pesticide registrations. Proc. Vertebr. Pest Conf. 14:8–11.

FELLOWS, D. P. 1977. Evaluation of new rodenticides and formulations. Synopsis of pelleted bait bioassays. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Prog. Rep.-Work Unit DF-103.7, Hilo, Haw. 22pp.

———, D. N. HIRATA, L. F. PANK, M. E. CROWELL, AND S. SATO. 1982. Comparative field efficacy of oat and pelleted zinc phosphide baits in Hawaiian sugarcane. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Job Completion Rep.-Work Unit DF-925.07, Hilo, Haw. 9pp.

———, AND R. T. SUGIHARA. 1977. Food habits of Norway and Polynesian rats in Hawaiian sugarcane fields. Hawaii. Plant. Rec. 59:67–86.

GUERRANT, G. O., AND J. W. MILES. 1969. Determination of zinc phosphide and its stability in rodent baits. J. Assoc. Off. Anal. Chem. 52:662–666.

HALVORSON, C. H. 1984. Long-term monitoring of small vertebrates: a review with suggestions. Pages 11–26 *in* J. L. Johnson, J. F. Franklin, and R. G. Krebill, coords. Proc. research natural areas: baseline monitoring and management. U.S. For. Serv. Gen. Tech. Rep. INT-173.

HILTON, H. W., W. H. ROBISON, A. H. TESHIMA, AND R. D. NASS. 1972. Zinc phosphide as a rodenticide for rats in Hawaiian sugarcane. Congr. Int. Soc. Sugar Cane Technol. 14:561–570.

HIRATA, D. N. 1977. Species composition of rats on Mauna Kea Sugar Company from 1967 through 1976. Hawaii. Sugar Technol. Annu. Conf. Rep. 36:91–94.

HOOD, G. A. 1972. Zinc phosphide—a new look at an old rodenticide for field rodents. Proc. Vertebr. Pest Conf. 5:85–92.

———, R. D. NASS, AND G. D. LINDSEY. 1970. The rat in Hawaiian sugarcane. Proc. Vertebr. Pest Conf. 4:34–37.

KARIM, M. A. 1983. Effects of zinc phosphide treatments on Hawaiian sugarcane rat populations. Ph.D. Thesis, Bowling Green State Univ., Oh. 186pp.

KAUKEINEN, D. E. 1984. Activity indices to determine trends in vertebrate pest populations. Pages 73–94 *in* A. C. Dubock, ed. Proc. on a conference on: the organisation and practice of vertebrate pest control. Imperial Chem. Industries PLC, Surrey, U.K.

KOEHLER, A. E., M. E. TOBIN, M. J. GOODALL, AND R. T. SUGIHARA. 1995. Weatherability of selected commercial zinc phosphide rodent baits. Int. Biodeterior. and Biodegradation 36:1–16.

———, ———, AND R. T. SUGIHARA. 1994. Effects of CS_2-starch xanthate on consumption by rats. Proc. Vertebr. Pest Conf. 16:113–117.

LEFEBVRE, L. W., N. R. HOLLER, AND D. G. DECKER. 1985. Efficacy of aerial application of a 2% zinc phosphide bait on roof rats in sugarcane. Wildl. Soc. Bull. 13:324–327.

———, ———, ———, AND N. J. SHAFER. 1978. Assessment of zinc phosphide-treated-bait acceptance by cotton, black, and Florida water rats and determination of acute oral toxicity of zinc phosphide to these species. Proc. Am. Soc. Sugar Cane Technol. 7:81–85.

LINDSEY, G. D., R. D. NASS, G. A. HOOD, AND D. N. HIRATA. 1973. Movement patterns of Polynesian rats (*Rattus exulans*) in sugarcane. Pac. Sci. 27:239–246.

LUND, M. 1988. Nonanticoagulant rodenticides. Pages 331–351 *in* I. Prakash, ed. Rodent pest management. CRC Press, Boca Raton, Fla.

MARSH, R. E. 1987. Relevant characteristics of zinc phosphide as a rodenticide. Proc. Great Plains Wildl. Damage Control Workshop 8:70–74.

NASS, R. D., J. K. CRIER, L. F. PANK, G. D. LINDSEY, AND D. N. HIRATA. 1971. Norway and black rat movements. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Annu. Prog. Rep.-Work Unit DF-103.7, Hilo, Haw. 22pp.

PANK, L. F. 1975. The effects of application rate, density and coverage on bait acceptance by canefield rats. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Job Completion Rep.-Work Unit DF-103.7-24, Hilo, Haw. 18pp.

———, D. N. HIRATA, R. T. SUGIHARA, D. P. FELLOWS, AND H. KAYA. 1976. The comparative efficacy of eight strip and four complete coverage applications of zinc phosphide bait on sugarcane. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Job Completion Rep.-Work Unit DF-103.7, Hilo, Haw. 8pp.

———, R. S. STOTT, AND D. N. HIRATA. 1973. Control of Norway rats with zinc phosphide in Hawaiian sugarcane. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Job Completion Rep.-Work Unit DF-103.7, Hilo, Haw. 6pp.

PEMBERTON, C. E. 1925. The field rat in Hawaii and its control. Bull. Exp. Stn., Hawaii. Sugar Plant. Assoc. Entomol. Ser. 17. 46pp.

PRAKASH, I. 1988. Bait shyness and poison aversion. Pages 321–329 *in* I. Prakash, ed. Rodent pest management. CRC Press, Boca Raton, Fla.

RICHARDS, C. G. J. 1988. Large-scale evaluation of rodent control technologies. Pages 269–284 *in* I. Prakash, ed. Rodent pest management. CRC Press, Boca Raton, Fla.

SAMUEL, A. C., B. W. COX, AND H. H. CRAMER. 1983. Implications of rising costs of registering agrochemicals. Crop Prot. 2:131–141.

SAS INSTITUTE INC. 1988. SAS/STAT user's guide. Version 6.03. SAS Inst. Inc., Cary, N.C. 1028pp.

SAVILLE, D. J. 1990. Multiple comparison procedures: the practical solution. Am. Stat. 44:174–180.

SHEPHERD, D. S., AND I. R. INGLIS. 1993. Toxic bait

aversions in different rat strains exposed to an acute rodenticide. J. Wildl. Manage. 57:640–647.

SUGIHARA, R. T., AND L. F. PANK. 1981. Comparative zinc phosphide bait bioassay on Polynesian, Norway and black rats. U.S. Fish and Wildl. Serv., Wildl. Damage Res. Stn., Job Completion Rep. 925.07, Hilo, Haw. 5pp.

———, ———, D. P. FELLOWS, D. N. HIRATA, R. S. STOTT, H. W. HILTON, AND H. KAYA. 1977. Noncrop habitat manipulation as a means of controlling rats and reducing damage to sugarcane. Hawaii. Sugar Technol. Annu. Conf. Rep. 36:84–90.

TOBIN, M. E., AND R. T. SUGIHARA. 1992. Abundance and habitat relationships of rats in Hawaiian sugarcane fields. J. Wildl. Manage. 56: 816–822.

———, ———, AND A. K. OTA. 1990. Rodent damage to Hawaiian sugarcane. Proc. Vertebr. Pest Conf. 14:120–123.

TOMICH, P. Q. 1970. Movement patterns of field rodents in Hawaii. Pac. Sci. 24:195–234.

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